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THE ROLE OF ALGAE IN AQUATIC ECOSYSTEMS, (U)

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cont' → algae assimilate large amounts of nutrients and trace metals during the growing season.

Nitrogen and phosphorous, present in sewage effluent and fertilizer, are two of the major nutrients required by algae. Excesses of these and other nutrients along with optimum conditions of light, temperature, turbidity, etc., can cause large algal growths (Eutrophication) to occur. These growths can cause toxicity, foul taste and odor, and a reduction in dissolved oxygen due to algal respiration and decomposition.

→ Detection and analysis of an algal problem can be accomplished by remote sensing, enumeration of phytoplankton, chlorophyll A measurements and carbon-14 uptake measurements. Once a problem is detected, an algicide, such as copper sulfate, is applied. The treatment of a lake with copper sulfate is accomplished in sections, otherwise, treatment of an entire lake may cause asphyxiation of fish due to algal decomposition, or toxicity due to copper or other herbicides.

→ Because of algae's importance in the aquatic food chain, endothall used in combination with other herbicides like diquat, silvex and copper sulfate to control certain aquatic plants, must be carefully used so toxicity of non-target organisms does not occur.

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THE ROLE OF ALGAE IN AQUATIC ECOSYSTEMS

INTRODUCTION

Algae and other aquatic plants play a major role in the functioning of aquatic ecosystems. They may act as shelters or substrates for many different types of invertebrates and fish. They reoxygenate the water by the process of photosynthesis and they form an important food base for the whole ecosystem. In the process of performing their function within the aquatic ecosystem they assimilate during the growing season large amounts of nutrients and also they may assimilate considerable amounts of trace metals which may be concentrated within the cells. It is also known that they excrete various soluble organic compounds which return elements such as nitrogen and phosphorous to the aquatic ecosystem. These then become food for various kinds of organisms.

The immediate effect on water quality is the removal of considerable amounts of nutrients and, in some cases, trace metals which are not known to be nutrients. These nutrients and trace metals are then locked up within the protoplasm of these plants. In the case of emergent vegetation, these nutrients are dispersed to the terrestrial ecosystem as well as being returned to the aquatic ecosystem in the form of detritus and directly as food.

Algae are found everywhere; in the air, in the soil, and in the water. This paper will be concerned with algae found in the water and particularly those algae found in reservoirs and lakes.

In water, algae may be found drifting on or within the water (phytoplankton), attached to a substrate (periphyton) or growing on other plants (epiphyton). Most phytoplankton are microscopic in size, while many periphyton can be seen with the naked eye (macroscopic). There are approximately 1500 genera and 17,400 species of algae. (1)

Ecosystem Energy Flow

The algae occupy a unique position among the organisms of the aquatic world because they are able to utilize light energy in the process of reducing CO_2 to the oxidation state of cellular carbon. As a result, the algae are an important link in the food chain and are often called the primary producers in aquatic systems. Because the algae are the ultimate source of both cellular carbon and chemical energy for other organisms in aquatic systems, the biological activity of an aquatic ecosystem is very much dependent upon the rate of primary production. The biological activity within the ecosystem is in turn affected by the physical environment.

The energy found as organic matter in the primary producers reaches the later stages of the food chain in several ways. Some of the organic matter excreted in soluble form or from decaying algal cells serves as nutrient material for the growth of heterotrophic bacteria. The algae as well as the bacteria may also be consumed directly and in this respect are a major source of food for the zooplankton and young fish. The principle importance of algae is, therefore, their ability to give rise to large quantities of organic matter in aquatic systems.

In the process of producing cellular carbon with the energy derived from photosynthetic processes, the algae acquire reducing power by using water as an electron donor. Oxygen is also produced from water as a by-product of the photosynthetic light reactions during daylight hours. As respiration is carried out by the nonphotosynthetic organisms, carbon dioxide is released and oxygen is consumed from the environment. For this reason, the levels of oxygen and carbon dioxide in aquatic environments depend to a large degree upon the relative rates of photosynthesis and respiration being carried on collectively by the algae, bacteria, and other organisms in the immediate area.

The algae make possible important chemical changes through the release of oxygen and the consumption of carbon dioxide during daylight hours. Oxygen is made available for respiration carried on by all types of organisms from fish to the smallest bacteria. The algae constitute the primary source for the continuous daytime renewal of essential oxygen in lakes and reservoirs. Oxygen release by algae and oxygen uptake by aeration are the two primary sources of oxygen in flowing surface waters. As algae remove carbon dioxide from their surroundings they cause an increase of the pH in surface waters. At night when photosynthetic activity is at a minimum, the reaction is reversed and the pH decreases.

Obviously, lakes and rivers normally contain many genera of planktonic and benthic algae. Limited numbers of algae are not troublesome, but rather a necessary link in the aquatic food chain. Algae frequently do become a problem in surface waters because of their capacity for rather prolific growth under certain conditions. Algal abundance varies with the

degree of enrichment with algal nutrients, the presence of toxic substances, temperature, turbidity, and other parameters. Under conditions where the proper nutrients are available, cell counts as high as 171,000 per ml have been recorded. Such large quantities of algal material are the usual cause of difficulties (eutrophication) in surface waters. The simple solution to the problems caused by excessive growths of algae would seem to be to have the proper kind of algae present in the appropriate amounts.

Growth and Nutrition

Algae need various elements as macro- or micronutrients to live, phytosynthesize, reproduce, etc. The macronutrients needed by algae are: carbon, hydrogen, oxygen, nitrogen, phosphorous, sulfur, potassium, magnesium and sodium. The micronutrients required by most algae are: iron, manganese, copper, calcium, zinc, molybdenum, vanadium, and zinc are needed during the photosynthetic process. Iron, calcium, boron, and molybdenum are associated with nitrogen utilization in most algae, and in the heterocyst* producing blue-green algae they are also needed for nitrogen fixation.

Water contains most of the elements needed by algae in ample supply from chemical actions occurring between the air-water, and water-substrate interfaces.

The major sources of nitrogen and phosphorous in water are: domestic sewage effluents; animal and plant processing wastes; fertilizer and chemical manufacturing spillage; and agricultural runoff (2). Nitrogen can also get into the water via the atmosphere, runoff from animal manure,

and the aforementioned nitrogen fixation by blue-green algae and bacteria. Additional phosphorous can be released into the water by the grubbing and burning of plant growth surrounding the shore line of a new impoundment (3).

Carbon can generally be obtained in adequate concentration for algal growth from the atmosphere (4). Additional carbon may be found in waters within calcareous basins since limestone yields considerable quantities of carbonate alkalinity (5). Other theorized sources of carbon are the respiration of bacteria and the extra cellular dissolved compounds of higher aquatic vascular plant communities (6). In a recent study of Norris Reservoir water (7) there was a significant increase in phytoplankton productivity when the concentrations of nitrogen and phosphorous were 0.10 mg/l and 0.05 mg/l, respectively. Nitrogen, phosphorous and even iron were limiting phytoplankton growth in Lake Travis during different times of the year (8). Laboratory studies indicated that the addition of phosphorous to the lake would enable nitrogen fixing blue-green algae to develop and produce additional nitrogen. Similar results were obtained in Lake Livingston, an eutrophic lake, simultaneously studied by the same researchers. Algal bioassay studies of Oregon lakes indicated algal growth rate to be directly proportional to total dissolved phosphorous concentrations but not to carbon and nitrogen concentrations (9). However, in general, no simple relationship exists between phytoplankton activity and nitrogen and phosphorous concentrations in water in which there is enough light to supply the energy needed for photosynthesis. Carbon dioxide depletion during photosynthesis may be an algal production regulating factor at very high levels of primary productivity (10).

Effects of Reservoirs and Lakes on Algae

Nutrients are not the only factors affecting algal growth in water impoundments. Algae as members of a biotic community in which they are primary producers, require optimum conditions of light, temperature, turbulence, grazing, predation rate, etc. to produce a bloom. Therefore, before we look at the effect of algae on water impoundments (which generally occurs only when they are in bloom condition) we should look at the effect of water impoundments of algae which lead to bloom conditions.

The location of a water impoundment can greatly affect algal conditions. Brylinski et al (11) states that algal productivity data from lakes within restricted latitudes are more easily compared by nutrient concentrations. However, on a global scale energy related variables appear to have a greater effect on algal productivity than those related to nutrient availability. Except for total nitrogen, nutrient concentration explains less than 15 percent of production variance whereas latitude alone explains about 57 percent. Corroborative results were obtained during a study of Lake Erken, a moderately eutrophic lake in central Sweden. Like many other lakes, the spring outburst of logarithmic algal growth was not caused by temperature but by solar radiation (12). Shallow lakes are more productive than deep lakes when they are compared on a production per unit volume basis.

Studies on Norris and Beech Reservoir (7,13) indicated that solar radiation either directly or indirectly controlled seasonal nutrient distribution and therefore governed primary productivity. Thus, even though more light is available for phytoplankton growth, productivity is

limited because the nutrient depleted epilimnion (i.e., the layer of water above the thermocline) cannot be restored by nutrients from the hypolimnion (i.e., the layer of water below the thermocline).

Additional research in the TVA system indicated that long water detention periods in lakes or reservoirs would increase phytoplankton growth because more of the nutrients in the "older" water would be in dissolved or particulate form (14). Furthermore, lake morphology and selective withdrawal of the water from storage impoundments can contribute to the separate aging of the hypolimnion and the epilimnion. Stated another way, the operation of a reservoir can affect phytoplankton growth. For example, before the Volta River system in Ghana, West Africa, was dammed, an initial decrease in phytoplankton was followed by an increase in density and diversity. The phytoplankton then stratified by the dam, for a while, until the generating plant began operation. The continual release of water reduced phytoplankton stability but increased phytoplankton concentration, which was dominated by Synedra acus, a diatom (15).

In general, hard water lakes have a greater abundance of algae than soft water lakes. This phenomenon is probably due to the increase in bicarbonate content. British Columbia lake studies indicated that total dissolved solids was the most important factor related to productivity yet plankton concentrations could not be predicted by fluctuation in this parameter (16).

The Petenwell Reservoir (17) receives high nutrient loadings from pulp and paper industries upstream of the reservoir. Previous nutrient studies indicated nutrient levels were adequate to support algal growth but most of the inorganic nutrients were probably used by the high level of bacterial activity. In addition, most of the light in the blue and red spectrum was absorbed in the top 40 centimeters of the reservoir. Thus, at this time there is no algal problem in Petenwell Reservoir but as the effluents from the upstream industries are reduced it is likely that algal growth in this over-fertilized reservoir will cause nuisance growths.

Algae get into lakes and reservoirs from the feeder waters, "seeding" from the gut or body surfaces of birds and insects, and from the air. Thus, there are many avenues for algal entry into a body of water. The two general classifications of problem-causing algae are phytoplankton and periphyton. For example, Cladophora spp. a green, filamentous, periphytic algae has caused problems in some of the Great Lakes because the abundant growths became detached during wave and wind action and washed up on the beaches. Once these growths were on the beach their decomposition produced a smelly general nuisance (1). Filamentous algae in general can remove the nutrients in a water body and thus prevent unicellular algae from developing. Unicellular algae are more desirable than filamentous because fish feed upon them, they do not interfere with various harvesting methods, and they do not provide a habitat for aquatic insect growths (16). Additionally, abundant growths of filamentous algae can block intake structures and trash racks. However, unicellular algae are not blameless since many of them can cause problems such as taste and odor in

the water, decreasing filter runs in water treatment plants, and forming unaesthetic green scums on the water.

Methods and Analysis

Many methods have been devised to determine if the algae present are causing actual or potential problems in the lake or reservoir. All of these methods have their advantages and disadvantages. One of the first methods devised was the enumeration of phytoplankton. This method is good for determining what species are present in the water but it tends to overemphasize large concentrations of small-celled organisms. Chlorophyll a is a measurement which provides as easy and relatively quick estimate of algal concentration but it overemphasizes the presence of large-celled phytoplankters. Carbon-14 uptake is a measurement of the vitality of the organism rather than the population size, but smaller algae generally photosynthesize more actively than larger forms and therefore incorporate Carbon-14 faster and more efficiently than larger forms (18). Bioassay procedures provide an indication of the effect of different variables on the lake or reservoir water; however, indigenous algae, bacteria, etc., can produce results that are quite different from those indicated in the bioassay test. Remote sensing is the newest form of monitoring a water body. Cameras containing films sensitive to different wave lengths are mounted in airplanes or satellites and are used to take synoptic views of the water body. At this time remote sensing, is primarily used for determining trouble areas such as algal bloom location or movement of bloom in relation to time. For remote sensing to be meaningful, ground crews should be in communication with the aerial crew and be able to sample those features noted by them.

While all of the above methods have their drawbacks they can all provide meaningful data if applied judiciously. For example, Mathis (19) studied a lake using chlorophyll a measurement and the ratio of "yellow/green" pigments. The researcher had to use judgment since one method indicated the lake was oligotrophic and contained a young immature ecosystem, whereas the ratio method indicated a mature ecosystem tending toward eutrophication.

Not only the method of algal sampling, but the location and season of sampling can reduce the errors and variance in sampling. Temperature, and thus the time of year samples are taken, can provide a different estimate of the species composition of a water impoundment. Some researchers indicate that optimum temperature for blue-greens are 15°-27°C; green algae 10°-21°C; and yellow-green algae 4°-10°C. Other researchers indicated 30°-40° to be the optimum temperature range for blue-green and 25°-35°C for green algae. Finally, one researchers contends that temperature is important for algal growth rate is rarely is directly involved in algae acclimatization (16). Thus it appears that more research is needed to determine the relationship between temperature and algae.

Another variable that adds to the difficulty of obtaining a meaningful algal sample is the lack of spatial homogeneity in algal distribution within a lake or reservoir. Various species of algal have different rates of floatation and sinking because of their shapes, oil contents and air vacuoles. Planktonic and benthic blue-green algae (20) develop in the hypolimnion, on or near the bottom of a water impoundment and as they

mature and develop gas vacuoles, they become buoyant and rise to the surface. A turbidimeter may be used for profiling the phytoplankton (21) to obtain a precise and rapid estimate of the phytoplankton population.

Thermal stratification and its breakdown to the isothermal condition are shock periods to the algae and various species may not survive these multiple shocks. Thus during these periods algal distribution and species may change. The application of fertilizer to a lake or reservoir can induce high concentrations of algae, as can the intensive use of herbicides which causes large concentrations of organic matter from the dead aquatic weeds resulting from treatment (22).

As a lake or reservoir becomes nutrient enriched there is an increase in algal concentrations, an increasing duration of high algal concentrations, and a decrease in diversity. In an eutrophic lake the primary productivity increases in early spring and continues at a high level throughout the summer. Blue-green algae are usually the dominant form in an eutrophic lake (23).

Nitrogen-fixing, toxicity, and taste and odor production are three reasons that blue-green algae are looked upon by some with disdain. Toxicity, and taste and odor production may be produced by some species in other algal groups but studies indicate that only heterocyst producing blue-green algae fix nitrogen (24). Heterocysts are produced when there is no combined nitrogen in the water but phosphates are present. The nitrogen-fixing allows other algae to utilize the nutrients in the water thus thwarting attempts to produce oligotrophication of a water body by removal of nitrates from influent waters. Algal poisoning in birds,

unlike botulinus poisoning, does not effect their nictating membranes (25). Most toxic algae are blue-greens, and the toxins they produce are generally not detoxified by the laboratory equivalent of water treatment (26). However, hepatic necrosis was produced in mice by feeding them Scenedesmus sp., a green algae (27).

As indicated by Palmer (28) every algal group found in fresh water contains species that produce taste and odor problems at certain levels of population density. Research is being performed on some of these organisms to isolate the taste and odor producing chemical. With this type of specific information, treatment methods can be devised to remove the specific nuisance when it occurs. One of the first taste and odor producing chemicals to be isolated was geosmin. This musty/earthy smelling metabolite of Oscillatoria spp. and Symploca spp. is a tertiary alcohol (29). Geosmin is said to inhibit Anabaena circinalis early in its life cycle and enhance it during the later stages. Another taste and odor producing chemical that has been isolated is the sulfur compound, isopropyl mercaptan, produced by actively growing Microcystis flos-aquae (=Anacytic cyanea) (30). In general, odor problems caused by blue-green algae can be controlled by activated carbon, whereas chlorination tends to intensify their odor. Addition of the bacteria Bacillus cereus from cultures has also proved effective. Some other methods of taste and odor control for blue-green algae that are being researched are: cell lysis by a weak electrolyte; viral and bacterial agents; and, slow release floating and sinking algicides (20).

Algal Management Methods

There are many methods of killing algae, but good management requires a tool that will affect the target organism and not seriously affect the rest of the biota in the ecosystem. One of the original tools used in water management, and which is still being used today, is copper sulfate. At present, this chemical is still the algicide most used by managers of reservoirs, canals, and waterways in general. Some managers, however, are now combining this compound with citric acid, or buying the pre-mixed cuprose citrate complex from various companies, to use in place of copper sulfate. Cuprose citrate is less sensitive to pH than copper sulfate and therefore is supposed to require a lower copper ion application for the same amount of algal control. A lower copper ion content in the water is advantageous since many fish are highly sensitive to this method. However, there are instances when cuprose citrate appears to provide no more algal control than copper sulfate.

To determine the correct dosage of copper sulfate one should know the algal species present, the density of the population and the condition of the receiving water. Some water resource managers have been able to attain algal control by trickling in low concentrations of copper ion, less than 0.1 parts per million, during certain seasons of the year. To do this a good history of the waterbody is needed as is some experimentation with the predominant nuisance algal species. The waters of the California State Water Project have a relatively high pH (i.e., usually in excess of 8.4) which tends to precipitate low dosages of copper sulfate to copper carbonate before there is any measurable uptake by the

algae. One part per million of copper ion, applied as copper sulfate pentahydrate, produces the needed control. Experiments are being performed to determine if less copper, applied in the form of cuprose citrate, would produce similar results. In application rate calculations for this chemical we include a factor for depth. For example, if the algal organism in bloom is found to a depth of 10 feet the amount of water to this depth is included in the calculation to obtain a one part per million dose.

There are two reasons that an entire lake is seldom treated with copper. If a heavy bloom of algae is treated with copper or any algicide their decomposition products will use the oxygen needed by fish, thus leading to asphyxiation of the fish. Additionally, as mentioned previously, copper is toxic to most fish. However, most healthy fish have an avoidance reaction to this chemical. Therefore, treatment methods should always provide for a chemical-free access to untreated open water. It is because of these reasons that most lakes undergoing a heavy algae bloom are generally treated in sections rather than in their entirety.

Copper sulfate is useful in killing most algal growths; however, since it is not specific and tends to accumulate in the benthos the entire ecosystem is affected by this chemical. Many chemicals have been formulated and researched for algicidal properties (32) and any of these when used correctly and at the right time, (i.e., as a preventive application rather than to remove existing blooms), will provide control. However, other methods that are less damaging to nontarget species, and the ecosystem in general, are desirable.

One method used for preventing algal blooms is the removal of nutrients from impounded waters. Eutrophication has become an increasing problem in lakes and reservoirs particularly since wastewater has undergone secondary treatment (33). This treatment produces a water with a higher degree of mineralization than does primary treatment. The nutrients in the mineralized state are more readily used by the algae. One method of nutrient removal researched, was the addition of low nutrient dilution water to lake water to reduce the blue-green algae population (34). This study indicates that the blue-green algae population was decreased without any significant effect on either green algae or diatoms. Another method for preventing algal blooms while depositing sewage into a lake or reservoir is to discharge the treated wastewater into the hypolimnion. This method is useful in deep lakes having a small surface area (35).

Biological Methods

There is a growing awareness on the part of those who are charged with the responsibility for any phase of environmental protection and management that aquatic macrophytes and associated organisms are important to the maintenance and enhancement of water quality. The control and management of these aquatic plants therefore becomes an important responsibility.

Aquatic macrophytes and even the tiny algae which occupy the same environment can be considered as weeds when they grow in profusion where they are not wanted. Although in general there was agreement throughout the conference relative to the types of aquatic plants which can be

considered harmful and unwanted it was often difficult to say that a species should be completely eliminated rather than reduced in numbers and managed. When biological control is considered, there are disagreements relative to the agents which should be employed, and the technology has not yet developed for practical application (36).

Herbicide Mixtures

Endothall is used in combination with other herbicides like diquat, silvex, and copper sulfate to control certain aquatic plants which are not controlled by endothall alone. Present knowledge of the effects of combinations of endothall with diquat, silvex, and copper sulfate is limited to their effects on target organisms, namely, that they result in an increased toxicity to certain aquatic plants (37-40). Algae and protozoa are two classes of microorganisms which are important links in the aquatic food chain and any adverse effects on these organisms may lead to significant changes in the aquatic ecosystem.

Six species representing two algal divisions were used in a study of non-target organisms Chlamydomonas reinhardi, Chlorella pyrenoidosa, and Scenedesmus obliquus (Chlorophyta) and Nostoc muscorum, Anacystis nidulans, and Anabaena variabilis (Cyanophyta). The Chlorophyta were obtained from the Culture Collection of Algae, Indiana University, and they were grown on Bristol's medium. The Cyanophyta were obtained from the Laboratory of Algal Physiology, University of Texas, and they were grown on Stainer's medium.

The species of protozoa used in this study was Tetrahymena pyriformis, obtained from the Gulf Breeze Environmental Research Laboratory, Gulf Breeze, Florida. The protozoan was grown axenically in a proteose peptone (2%, w/v) medium, supplemental with 0.1% (w/v) dehydrated yeast extract and 0.5% (w/v) glucose. The cultures were grown on a reciprocating shaker (300 rpm) at $26 \pm 1^{\circ}\text{C}$. For toxicity studies, 50 ml of cell suspension (1×10^4 cells/ml) were incubated in 300 ml erlenmeyer flasks containing an appropriate concentration of herbicide combination. After 1, 2, 3, 4 and 7 days, growth was determined by measuring the absorbance of 540 nm. (41,42,43,44).

Endothall + Diquat: The only significant effect of endothall was a stimulation in the growth of Nostoc (0.00447 - 0.447 ppm) and a small inhibition in the growth of Chlamydomonas (4.47×10^{-5} - 0.447 ppm), both after 14 days. At 0.552 and 0.276 ppm, diquat completely inhibited growth of all the algae except Scenedesmus. Growth of Scenedesmus was reduced 21% and 11%, respectively, after 14 days. The blue-green algae were more sensitive to diquat than the green algae. Growth was completely inhibited by diquat at 0.552 and 0.276 ppm and 0.055 ppm inhibited growth by 5-15%. Inhibition of growth by combinations of endothall + diquat (1×10^{-4} - 1.0 ppm) was similar to that for diquat alone. However, diquat (0.055 ppm) alone and in combination with endothall (0.0447 ppm) caused an increase in the growth of Chlamydomonas.

The inhibition of growth by a mixture of diquat and endothall resulted from the effect of diquat since diquat alone (0.276 and 0.552 ppm) was as toxic as a combination of diquat (0.276 and 0.552 ppm) and endothall (0.223 and 0.447 ppm).

Endothall + Silvex: Endothall (0.47 - 4.65 ppm), silvex (0.053 - 5.33 ppm) and combinations (0.1 - 10.0 ppm) of endothall + silvex had no significant effect on growth of Chlorella, Scenedesmus or the blue-green algae. Endothall (4.65 ppm) or silvex (5.33 ppm) alone reduce the growth of Chlamydomonas 5% and 9%, respectively, after 14 days. All of the concentrations (0.1 - 10 ppm) of endothall + silvex were more toxic to Chlamydomonas than the individual herbicides which may indicate a synergistic effect of the herbicides.

Endothall + Copper Sulfate: Growth of Scenedesmus was stimulated by endothall alone (0.33 - 1.66 ppm) while growth of Chlorella and Chlamydomonas was not affected. Copper sulfate alone (0.66 - 3.32 ppm) had no effect on the growth of the green algae. The only effect of the combinations of endothall + copper sulfate (1-5 ppm) was a decrease in growth of Chlamydomonas after 7 days. However, the cultures had recovered when the experiment was terminated (14 days).

The blue-green algae were more sensitive to copper sulfate than the green algae. Algal growth was totally eliminated by 0.66, 1.66, and 3.32 ppm copper sulfate, while endothall alone (0.033 - 1.66 ppm) had no effect, Anacystis was more sensitive to copper sulfate than either Nostoc or Anabaena. Growth of Anacystic was completely inhibited at 0.33 ppm, while any inhibition in the growth of Nostoc and Anabaena was less than 8%. Treatment of Anacystis with 0.5 ppm endothall + copper sulfate also caused a complete inhibition of growth of this algae.

Effect on the Growth of Protozoa: Endothall in combination with diquat, silvex and copper sulfate had little effect on the growth of Tetrahymena.

Exposure of Tetrahymena to mixtures of endothall and silvex caused some growth inhibition three days after treatment. However, this inhibition generally disappeared within 24 hours and the organism resumed normal growth.

Summary and Conclusions

It is evident that the control of aquatic plants for the purpose of water quality enhancement is a very complex matter. A legion of methods of control are available. However, no single method seems to be outstandingly good. Instead, it appears that the control or management problem will differ in each geographical area and perhaps for each body of water. The solution then would appear to be an integrated type of control administered by well-informed, intelligent people who can tailor the procedure to the needs of the locality or body of water. At present the "state-of-the-art" is such that we need to devote more time to pertinent experimentation and to the type of research which will provide the answer needed to design a comprehensive and fully integrated management plan.

Treatment of aquatic microorganisms with endothall in combination with other herbicides like diquat, silvex and copper sulfate, at the recommended rate of active ingredients for each mixture (0.25 - 0.5 ppm, endothall + diquat; 2 - 6 ppm, endothall + silvex; 1.5 - 4 ppm, endothall + copper sulfate) did not significantly affect growth of the protozoan Tetrahymena. However, these herbicide combinations are more toxic to the phytoplankton.

Endothall and silvex combinations did not significantly affect the green or blue-green algae, except Chlamydomonas which was slightly inhibited. Endothall and diquat combinations were highly toxic to all the algae. Treatment of the algae with a concentration within the range of recommended rates substantially reduced the growth of the organisms tested. Combinations of endothall and copper sulfate did not significantly alter growth of the green algae, but were toxic to the blue-green algae. Treatment with endothall + copper sulfate mixtures might be used as a method for selectively reducing blue-green populations without significantly harming the green algae.

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